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AD-A198 199 ATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
Test Operations Procedure 2-2-625

5. MONITORING ORGANIZATION REPORT NUMBER(S)
same as item 4

6a. NAME OF PERFORMING ORGANIZATION
U.S. ARMY COMBAT SYSTEMS TEST ACTIVITY

6b. OFFICE SYMBOL *(If applicable)*
STECS-AD

7a. NAME OF MONITORING ORGANIZATION
U.S. ARMY TEST & EVALUATION COMMAND

6c. ADDRESS *(City, State, and ZIP Code)*
ABERDEEN PROVING GROUND, MARYLAND 21005-5059

7b. ADDRESS *(City, State, and ZIP Code)*
ABERDEEN PROVING GROUND, MD 21005-5055

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
(same as item 7a)

8b. OFFICE SYMBOL *(If applicable)*
AMSTE-TC-M

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*
(same as item 7b)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
AMC-R	310.6		

11. TITLE *(Include Security Classification)*
"MUZZLE BLAST DAMAGE TO COMBAT VEHICLES" (U)

12. PERSONAL AUTHOR(S)

13a. TYPE OF REPORT Final

13b. TIME COVERED FROM ______ TO ______

14. DATE OF REPORT *(Year, Month, Day)* 1988 August 16

15. PAGE COUNT 15

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Combat vehicles Self-propelled artillery
Muzzle blast overpressure

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*
Describes testing procedures for evaluating the effect of muzzle blast and firing shocks on combat vehicles and their components.

Supp AD-871819

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE *(Include Area Code)*

22c. OFFICE SYMBOL

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

88 8 22 077

U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-101
*Test Operations Procedure 2-2-625 — 16 Aug. 1988
AD No.

MUZZLE BLAST DAMAGE TO COMBAT VEHICLES

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1. SCOPE. This TOP provides tests for evaluating damage to combat vehicles (self-propelled artillery and assault vehicles) and their components by muzzle blast. Muzzle blast overpressure can affect the structural integrity of weight-restricted vehicles. Measuring blast pressure loading and resultant stress can provide a basis for predicting damage that will occur when the weapon is fired.

Two methodologies are presented in this TOP to determine the effects of blast overpressure on a test vehicle. The first methodology assesses combined forces of recoil energy and blast overpressure. This is accomplished by firing an instrumented test vehicle and measuring the resultant strain, acceleration, and blast overpressure effects imparted to the vehicle. The second methodology separates the effects of blast overpressure from recoil forces. This is accomplished by firing an instrumented test vehicle and measuring the resultant strain, acceleration, and blast overpressure. Then, fire a second vehicle, identical to the first, from a position to impart a worst case blast overpressure wave onto the test vehicle; measure the blast overpressure.

These tests will yield data describing the pure blast effects and blast/recoil effects upon the test vehicle. The results of these tests will enable test personnel to ascertain which forces cause structural damage to the vehicle. These results will be used to correct design deficiencies.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM

Photographic equipment

Applicable test items

*This TOP supersedes MTP 2-2-625 dated 27 October 1969.

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2.2 Instrumentation.

DEVICE FOR MEASURING:	PERMISSIBLE ERROR OF MEASUREMENT*
Blast overpressure (in accordance with TOP 4-2-822[1]**)	5-10% or as determined by test purpose and cost
Weapon chamber pressure (in accordance with ITOP 3-2-810[2])	2%
Strain	
Acceleration ("g" loads)	
Meteorological data:	
Wind direction	3%
Wind speed	1 m/s
Ambient temperature	2° C
Relative humidity from 5% to 100%	1%
Barometric pressure	1 mm

3. REQUIRED TEST CONDITIONS.

3.1 Selecting and Locating Transducers.

a. In preparation for testing, do the following:

(1) Review pertinent literature about the test vehicle/weapon system, including requirements documents and applicable military specifications in order to identify problem areas. Examine background data for any available blast overpressure measurements, including 140-dB contours. If this information is not available for the test vehicle/weapon system, attempt to establish the 140-dB contour for the particular test item in accordance with the procedures in TOP 1-2-608.[8] Per reference 7, the 140-dB level is impulse noise limit below which no protection is required. If a 140-dB contour cannot be established due to test constraints, use data for weapons of similar characteristics that use comparable ammunition components for planning purposes.

(2) Stress coat applicable areas; fire one round lower charge, examine stress coat, fire next higher charge, etc.

b. Transducer Locations.

(1) Based on the above, select positions at which transducers should be situated (e.g., at crew positions, ammunition racks, sights, radios, engine compartments, battery compartments) in accordance with a definite and repeatable plan that will permit the test results to be used by other agencies in correcting design deficiencies. Figure 1 shows a typical gauge layout, including strain gauges, accelerometers, and transducers for measuring blast overpressure. NOTE: The type and number of transducers to be used depends on the precision required and the test objectives.

*The permissible error of measurement for instrumentation is the two-sigma value for normal distribution. Thus, the stated errors should not be exceeded in more than one measurement of 20.

**Footnote numbers correspond to reference numbers in Appendix B.

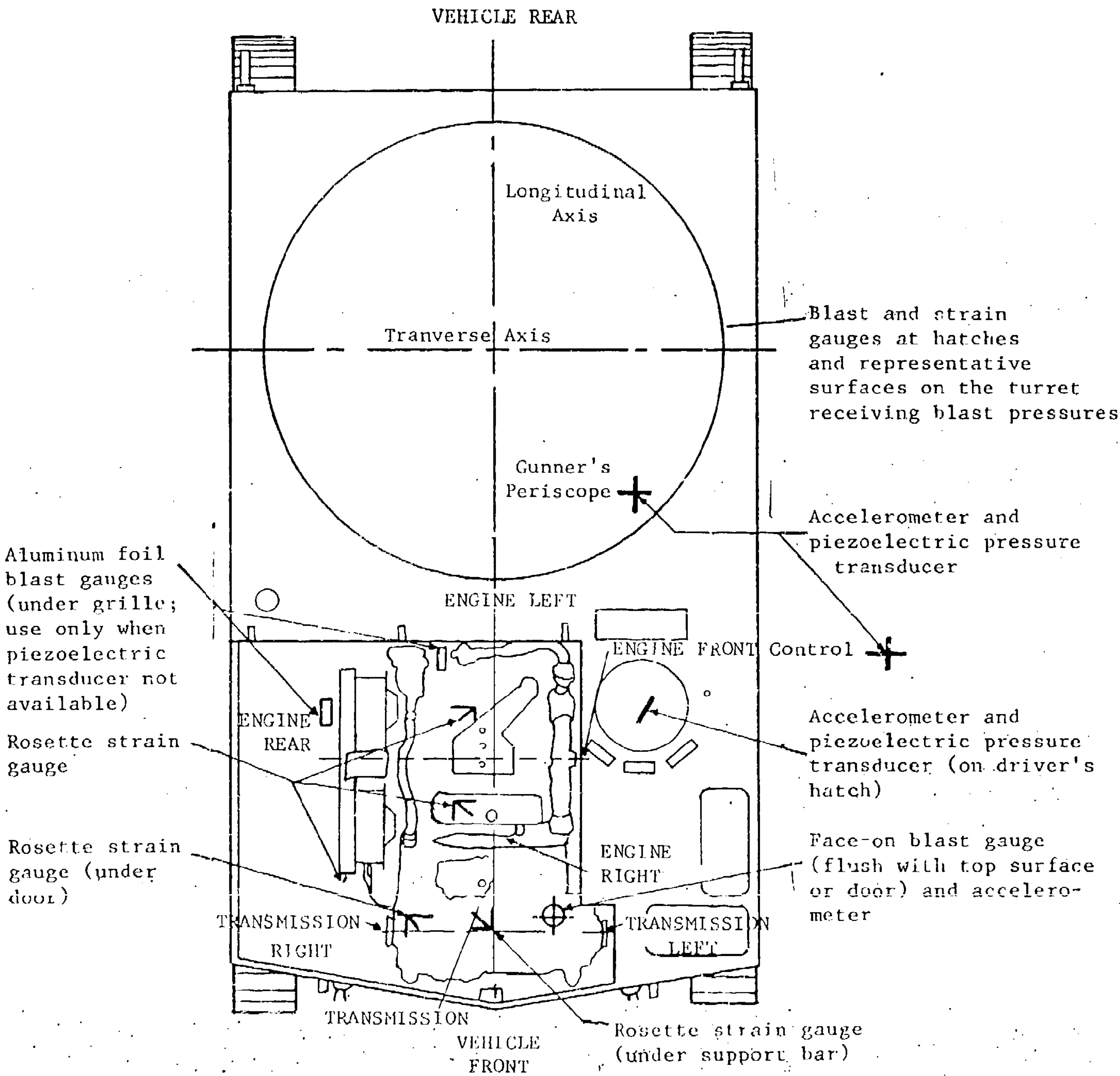

Figure 1. Location and orientation of gauges.

(2) From the blast contour, determine the location at which a second or donor test vehicle/weapon system should be placed to impart the worst case blast overpressure to the accepting test item when the donor is fired. NOTE: The donor vehicle does not need to be instrumented since it is used solely to provide a muzzle blast overpressure wave to the acceptor vehicle/weapon system.

c. Select pressure transducers, accelerometers, and strain gauges to be used at each location based on the following considerations:

(1) Expected peak overpressure
(2) Distance from source to gauge
(3) Total number of locations involved
(4) Type of material (e.g., metal, ceramic, plastic) of which the test component is made
(5) Configuration and accessibility of test components

3.2 Instrumentation.

a. Attach strain gauges and accelerometers, and install pressure transducers at the locations selected in accordance with instructions contained in TOPs 4-2-822, 3-1-006[3], and 4-2-823[4], as applicable. NOTE: The wire-sensing elements of strain gauges should preferably be mounted parallel to either the transverse or longitudinal centerlines of the vehicle, whichever is more nearly parallel to the principal axis of strain. If the direction of the principal strain is unknown, it should be determined by use of TOP 1-2-605[5] or TOP 3-2-809[6].

b. Determine and record the location and identification of each gauge, accelerometer, and pressure transducer with respect to both the acceptor vehicle and the donor vehicle.

c. Connect all electronic gauges to the instrumentation trailer and perform necessary calibration checks.

d. Aluminum foil gauges are occasionally used to approximate bounds of peak pressures. If possible, piezoelectric pressure transducers should be used at all locations. If foil gauges are required, emplace new ones before firing each round. NOTE: Since replacement of foil is time-consuming, assemble a group of these gauges before firing to permit their immediate replacement after each round. Foil gauges described in reference 9 should be used. These gauges provide a more accurate representation of the peak pressure wave than foil gauges previously used.

3.3 Weapon Servicing. Before testing, service and check the weapons as specified in the applicable standing operating procedure.

4. TEST PROCEDURES.

4.1 Acceptor Vehicle Firing. Unless directed otherwise, fire the weapon in accordance with Table 1 for each type round specified in the test directive. Insert weapon pressure gauges in the chamber with propellant. Conduct firing tests using the following procedures:

a. After the weapon is laid on the designated azimuth (line of fire) and elevation, measure and record the position of each transducer relative to the muzzle of the weapon to be fired.

b. Photograph typical test setups.

c. Measure and record all applicable meteorological data.

d. Observe the weapon and test vehicle during firing of each test round, and record weapon and ammunition data and any vehicle movement.

e. Photograph typical muzzle flash conditions (preferably at night) for each type of round using color film to provide a visual record of the magnitude of the blast.

f. Record blast, acceleration, and strain gauge data and peak weapon chamber pressure for each round fired. For crew locations, calculate peak pressure and "B" duration in accordance with MIL-STD 1474B.[7]

g. Visually inspect the test vehicle; record all evidence of part failures or deformations.

h. Photograph all evidence of damage to the test vehicle.

4.2 Donor Vehicle Firing. Unless otherwise directed, fire the weapon in accordance with Table 1 for each type round specified in the test directive. Insert weapon pressure gauges in the chamber with propellant. Conduct firing tests using the procedures in 4.1.a through 4.1.h above.

5. DATA REQUIRED. Record the following:

a. For each blast gauge, strain gauge, and accelerometer:

Type gauge
Identification number
Exact location relative to fixed reference point on vehicle
Orientation

b. During testing:

Position of each gauge and accelerometer relative to muzzle of weapon being fired

Meteorological data:
Wind direction
Wind speed
Ambient temperature
Barometric pressure
Relative humidity
Type day (rainy, clear, etc.)

c. For each round fired:

Time each round fired
Round number
Nomenclature of vehicle and weapon
Complete list of ammunition components
Type and size propelling charge

Additives use in propelling charge (e.g, flash reducers)
Weapon azimuth and elevation
Type muzzle device, if any
Degree of muzzle flash and smoke
Evidence of vehicle movement
Blast, strain gauge, and accelerometer data

Peak chamber pressure for each round
Evidence of part failures or deformation
Photographs of the following:
Test setup for each weapon attitude
Typical muzzle flash
Damage to test vehicle

TABLE 1. FIRING SCHEDULE.

Round No.	Type Charge or Round	Weapon Attitude Elevation	Traverse
	--Firing Acceptor Vehicle--		
1,2	service	zero	
3	PIMP		
4,5	service	mean	center, front
6	PIMP		
7,8	service	maximum	
9	PIMP		
10,11	service	zero	
12	PIMP		
13,14	service	mean	right, max.
15	PIMP		
16,17	service	maximum	
18	PIMP		
19,20	service	zero	
21	PIMP		
22,23	service	mean	left, max.
24	PIMP		
25,26	service	maximum	
27	PIMP		
28,29	service	zero	
30	PIMP		
31,32	service	mean	center, rear
33	PIMP		
34,35	service	maximum	
36	PIMP		
	--Firing Donor Vehicle--		
37,38	service	zero	
39	PIMP		
40,41	service	mean	center, front
42	PIMP		
43,44	service	maximum	
45	PIMP		

NOTES: 1. Limits of elevation and traverse depend on weapon design.

2. Additional rounds can be fired at the discretion of the test director.

3. Before firing each round, re-orient all blast gauges toward the muzzle.

6. DATA PRESENTATION. All transducer locations will be shown on a sketch or drawing representing the test item and the donor vehicle. The peak (positive and negative) and root mean square (rms) strain and acceleration values will be tabulated. The blast overpressure data will be tabulated to present peak pressures (in units of decibels, kPa, and lb/in^2), as well as the pressure wave duration (msec). Strain, acceleration, and blast pressure versus time plots will be prepared to validate peak values.

Blast overpressure data will be presented in a tabular format, including peak pressure, total energy, "A" weighted energy, "A" duration, "B" duration, and noise levels (dB). Blast data can easily be converted to noise levels (dB) for determining blast exposures of crew members (TOPs 1-2-608[8] and 4-2-822). Use the technique described in MIL-STD-1474B for calculating peak pressure, "B" duration, and allowable number rounds per day.

From the strain measurements, time durations, and a knowledge of the metals involved, determine the resulting stresses and their relationship to the material yield point. Consideration should be given to stresses that are not above the yield point but could result in damage due to the cyclic effect of repeated firings.

From the acceleration measurements and time durations, a power spectral density plot is derived to determine the frequency response of the material at the accelerometer location. Knowledge of the material properties can then be used to identify structural weaknesses.

Compare the strain, acceleration, and blast overpressure data which were recorded when firing the acceptor weapon, with the data recorded from firing the donor weapon. In this manner, recoil shock effects can be isolated from the combined effects of blast pressure and recoil shock. This comparison should prove valuable in determining the primary cause of test vehicle/weapon system damage when firing the weapon system. The blast pressure data can be used in conjunction with applicable surface areas to determine the forces exerted on these areas. Possible structural failures may be predicted in this manner.

Perform extrapolation and interpolation of blast, strain, and acceleration measurements to assess firing conditions or transducer locations which were not tested. The focus should be on areas of the test item that were either damaged or could potentially cause damage through repeated firing.

Based on the previous paragraphs, make recommendations for re-design or improvement of vehicle components which are deficient.

Typical data presentation forms are shown in Appendix A.

Recommended changes of this publication should be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TC-M, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity: Commander, U.S. Army Combat Systems Test Activity ATTN: STECS-AD, Aberdeen Proving Ground, MD 21001-5059. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the accession number (AD No.) printed on the first page.

APPENDIX A

TYPICAL TYPES OF DATA PRESENTATION

TABLE A-1. ROUND-BY-ROUND DATA.

			Pressure Data				
			Gauge No. 1		Gauge No. 2		
Round No.	Elev deg	Charge zone	Serial No.	Pressure kPa/100	Serial No.	Pressure kPa/100	Avg. Pressure kPa/100
Date fired: 2 May 1988							
Projectile seating: 29-5/8 in.							
Propelling charge: M4A1							
Propelling charge lot: BAJ-63380							
1	0	7				not taken	
2	0	7				not taken	
3	0	7				not taken	
Propelling charge: XM119							
Propelling charge lot: RAD-64651							
4	0	8					
5	0	8	10016	3261	7720	3247	3254
Propelling charge lot: RAD-64645							
6	0	8	3436	3358	4075	3365	3365
7	35	8	10917	3289	9450	3241	324[illegible]
Date fired: 5 May 1988							
Projectile seating: 29-1/2 in.							
8	35	8	2621	3330	9609	3351	3337
9	35	8	9768	3365	9495	3365	3365
Propelling charge: M4A1							
Propelling charge lot: BAJ-63380							
10	35	7	8681	2461	6866	2503	2482
11	35	7	923	-	4439	-	-
12	35	7	7716	2510	9642	2496	2503
Date fired: 9 May 1988							
13	0	7	9394	2510	7774	2530	2517
14	0	7	9494	2496	2225	2489	2496
15	0	7	9472	2496	4031	2510	2503

TABLE A-2. SUMMARY OF BLAST DATA FOR 155-MM HOWITZER, SP, M109.

Muzzle Blast Investigation

Muzzle Blast Overpressure, kPa
Gauge Position

Round No.	Control	Gunner	Driver	Engine Compartment Door[a]
QE: 0 degree; propelling charge: zone 7, lot BAJ-63380, M4A1				
1	9.5	3.9/9.2[b]	16.5/30.3	41.3/45.1
2	9.4	5.4/9.3	19.6/32.5	39.2/53.2
3	8.8	8.7/10.3	17.3/33.3	38.8/70.5
13	9.3	-	-	-
14	9.4	-	-	-
15	9.4	-	-	-
QE: 0 degree; propelling charge: zone 8, lot RAD-64651, XM119				
4	13.7	10.9/16.5	11.3	74.7/104.3
5	13.2	16.9	39.8	83.6/107.6[c]
6	12.1	15.6	42.0/45.0	76.2/111.7[c]
16	15.2	-	-	-
17	13.8	-	-	46.1/95.9/105.3
18	14.4	-	-	107.0[c]

[a]Overpressure on engine compartment door is "face-on" pressure. All other pressures are "side-on".

[b]When two pressures are presented, e.g., 3.9/9.2, the first value is the initial pressure and the second value is the reflected pressure. The reflected pressure is presented only when it is greater than the initial pressure.

[c]Scope limit - recorded trace went off scope.

TABLE A-3. MAXIMUM PRINCIPAL STRESSES.

QE, deg	Compression, lb/in² Zone 7	Zone 8	Change,%	Tension, lb/in² Zone 7	Zone 8	Change,%
Engine compartment door (underside)						
0	27015	62719	+132	17992	32424	+80
35	5765	10818	88	11412	15570	36
Engine compartment door support						
0	13030	23329	79	14921	19083	28
35	10207	15224	49	9797	13379	37
Rocker arm assembly cover (front)						
0	12868	63646	395	25418	35424	39
35	15008	23357	56	25071	32858	31
Rocker arm assembly cover (rear)						
0	66348	82919	25	68267	75265	9
35	62201	93003	50	68336	79340	16
Radiator tank						
0	5082	16146	218	3704	4982	35
35	6644	8725	31	4922	7393	50

Note: A typical strain versus time oscilloscope record is shown in Figure A-2.

TABLE A-4. SUMMARY OF STRAIN DATA FOR 155-MM HOWITZER M109 MUZZLE BLAST INVESTIGATION.

Right Front Engine Compartment Door (Underside)

Round Number	Strain x 10^{-6} in./in. ϵ_a	ϵ_b	ϵ_c	Principal Stress $\sigma1$psi	$\sigma2$psi	Axis°	Principal Strain x 10^{-6} in./in. ϵ_1	ϵ_2	Time ms
QE: 0°	Propelling Charge: Zone 7, Lot No. BAJ 63380, M4A1								
1	-117	-154	-273	-6314	-10381	13.9	-107	-283	1.1
	-71	-490	-390	-2835	-16933	-29.3	75	536	3.5
	65	0	-412	-641	-14254	18.0	121	-469	4.4
	246	6	117	12095	3465	-34.9	369	-5	6.5
	214	451	262	15138	5245	19.8	452	23	10.5
	149	177	468	17992	8451	-41.8	515	102	12.9
2	-67	-506	-566	-8314	-18814	-18.6	-89	-544	4.3
	242	-3	-264	5909	-6852	0.9	-267	265	5.3
	-29	119	481	16909	2463	11.4	539	-87	11.5
	-41	259	376	13017	1340	-11.8	420	-86	12.7
	-310	43	350	8496	-6781	-2.0	351	-311	13.6
3	-78	-146	-475	5562	-18438	16.7	9	-562	1.9
	41	312	-112	6684	-9770	38.8	320	-393	2.9
	-138	-552	-433	-4355	-20116	-30.5	56	-627	4.8
	223	-115	-336	4605	-9448	-5.9	248	-361	5.5
	-113	210	569	15252	4291	1.5	465	-9	12.8
	-306	120	-427	-4399	-27015	41.4	124	-857	15.4

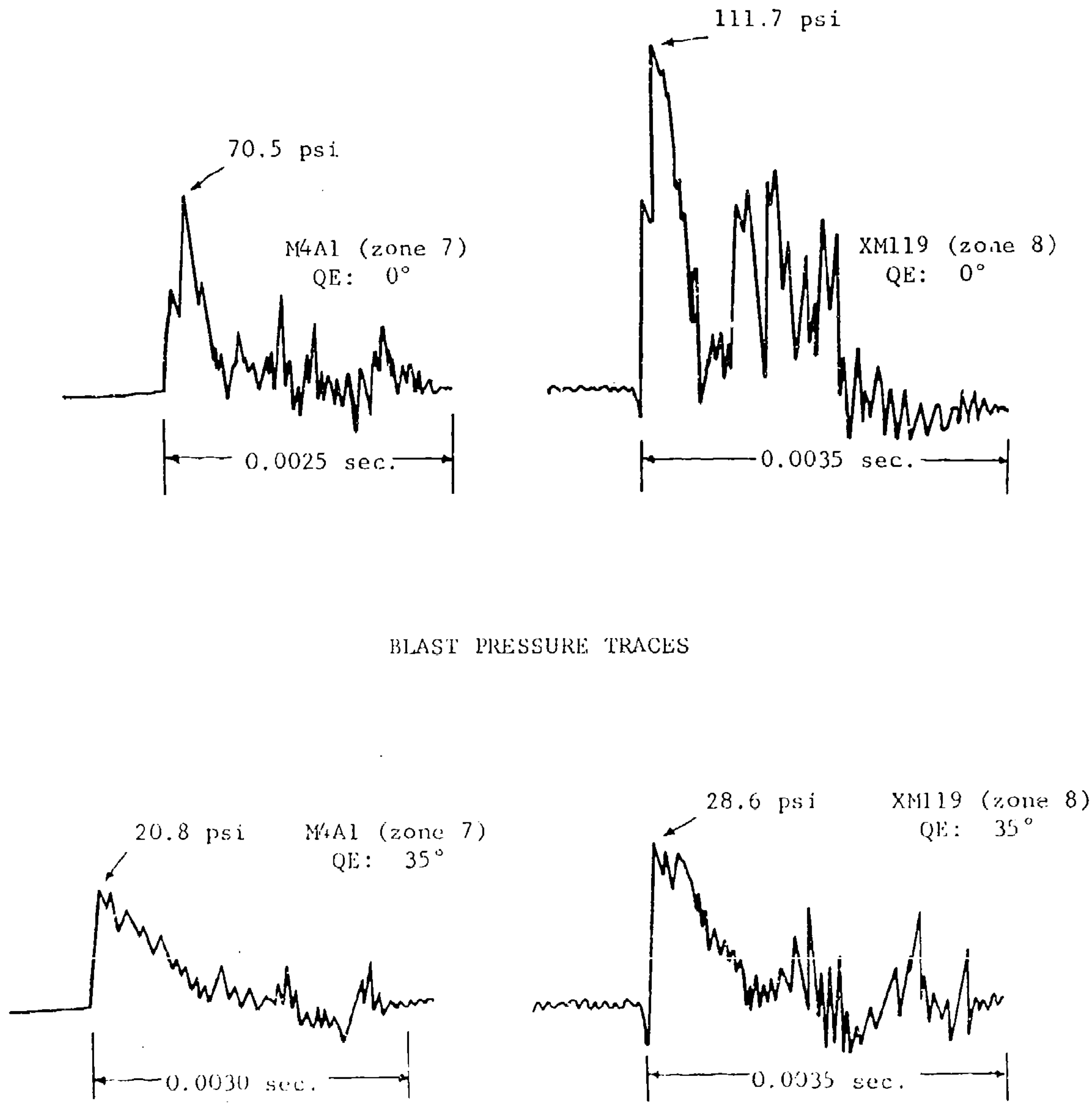

Figure A-1. Blast pressure traces (engine compartment door).

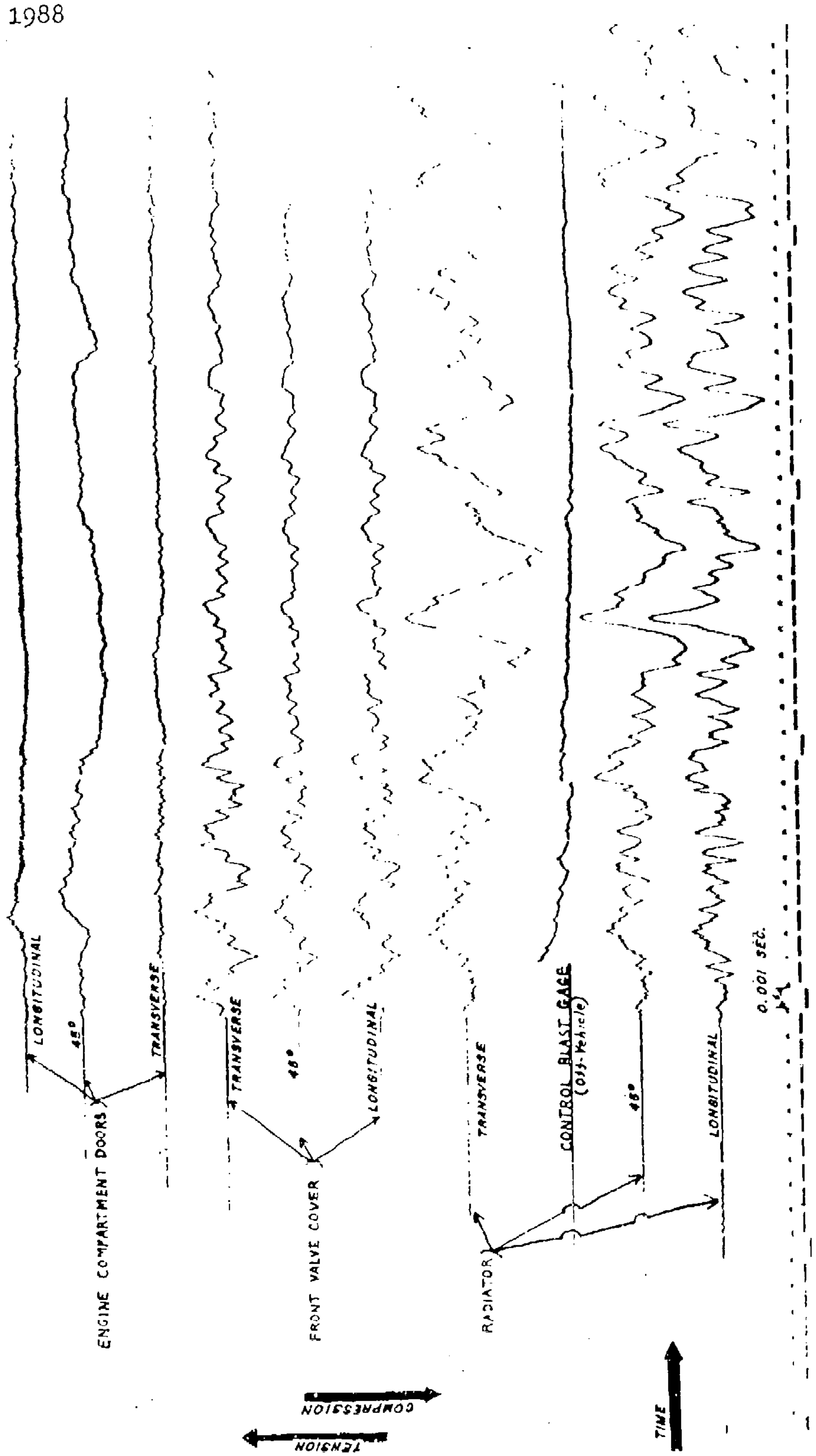

Figure A-2. Typical strain versus time records.

APPENDIX B

REQUIRED REFERENCES

1. TOP 4-2-822, Electronic Measurement of Airblast Overpressure, 8 September 1981.

2. ITOP 3-2-810, Weapon Chamber Pressure Measurements, 18 December 1985.

3. TOP 3-1-006, Strain Measurement - Unidirectional, 20 April, 1983.

4. MTP 4-2-823, Paper Blastmeters, 2 November 1966.

5. TOP 1-2-605, Birefringent Coating Technique of Photoelastic Stress Analysis, 28 August 1980.

6. TOP 3-2-809, Brittle Lacquer Technique of Stress Analysis, 29 July 1981.

7. MIL-STD-1474B(MI), Noise Limits for Army Materiel, 18 June 1979.

8. TOP 1-2-608, Sound Level Measurements, 17 July 1981.

9. BRL TR-2783, Design of Non-Discrete Diaphragm Pressure Gauges for Blast Pressure Measurements, March 1987.